Innovative Technologies 1.1

What are technical solutions for lightweight BIPV?

Most facades can accommodate glass photovoltaic products [cf sheets 1.2 and 1.4]. Lightweight BIPV modules extend the range of possibilities for the cladding of buildings, especially for renovation projects. Here a new, reliable solution is presented.

In some circumstances, the relatively high weight (≥15 kg/m^2) of existing glass/glass building-integrated photovoltaics (BIPV) modules may constitute a barrier to the diffusion of PV in the built environment. With the aim of reducing weight while preserving excellent mechanical stability and durability properties, we propose a new design for lightweight crystalline-silicon (c-Si) PV modules in which the conventional polymer backsheet (or glass) is replaced by a composite sandwich structure and the glass frontsheet by a transparent polymer foil.

Keywords: Solar Module; Crystalline-Silicon; Building-Integrated Photovoltaic (BIPV); Lightweight.
Target audience: Suppliers and companies.

In this study [1-3], we propose a **lightweight PV module** based on c-Si technology with a weight of ~6 kg/m^2. To reach this low weight, the standard front-glass is replaced by a thin polymeric sheet and the standard backsheet replaced by an innovative composite sandwich structure bringing the needed mechanical stiffness to the module. Fig. 1 shows all the materials used to produce the lightweight PV module, which includes a composite sandwich structure (composed of two skins and one core joined together with an adhesive), solar cells embedded in a polymer layer (EVA) and protected by a thin frontsheet (ETFE). Furthermore, our lightweight PV module can be processed in a **single manufacturing process** (including the processing of the composite sandwich backsheet).

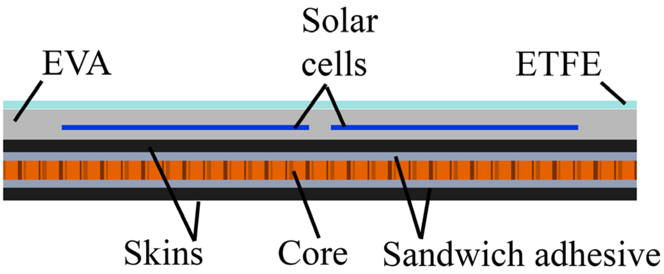

Fig. 1 Sketch of our ultra-lightweight PV module design developed for BIPV applications with description of all layers (image taken from [1]).

The composite sandwich structure is responsible to provide the required rigidity to the PV module, thus this is the main component of the lightweight module. However, the main challenges during the design of such modules is to find a PV polymer adhesive that will provide a good stress transfer through the sandwich structure. Due to the use of different stacked materials with different thermal properties, the difficulty is to avoid early failure of the structure (composite sandwich) during a sub-set of IEC 61215 2:2016 industry standard qualification tests.

Fig. 2 and 3 show how the thermo-mechanical properties (high vs low stiffness) can influence the resistance and stability of our backsheets to thermal cycles and stresses.

FNSNF Swiss National Science Foundation
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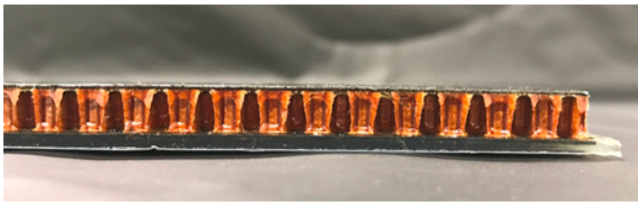

Fig. 2 Visual inspection of the composite lightweight module produced using a good sandwich adhesive.

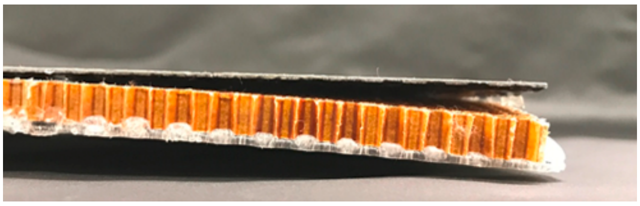

Fig. 3 Visual inspection of the composite lightweight module produced using a bad sandwich adhesive.

Thanks to optimal material selection (Fig. 2) and manufacturing parameters, medium-area modules composed of sixteen solar cells (81 cm x 81 cm) are manufactured using a standard flat-bed vacuum bag laminator, and processed in only 25 minutes. To pre-qualify our design, we used the relevant ac-celerated-aging test in use in the industry [4], which includes:

1. **Thermal cycling test** - module is exposed to cyclical temperatures between 85°C and -40°C (200 cycles).
2. **Damp heat test** - module is exposed to a temperature of 85°C and a relative humidity of 85% for a period of 1000 hours.
3. **Humidity freeze test** - module is subjected to cyclical temperatures between 85°C (with rela-tive humidity of 85%) and -40°C.
4. **Hail test** - module is shot at from different positions by ice balls of diameter ranging from 25-75 mm at specific velocities (23-39.5 m/s).
5. **Static mechanical load test** - module is loaded on the front side with 2400 Pa for 1h and af-terwards with -2400 Pa for an additional 1h (3 cycles).

Preliminary results indicate that with a careful selection of the materials and consideration of the manu-facturing process, we are able to obtain light and robust solar PV modules that are able to pass the most demanding industry qualification tests. The next challenge will be to develop medium-area devices (Fig. 4) with the aim to further upscale the size of our prototypes to that of commercially available modules (~1x1.6 cm^2 with 60 cells).

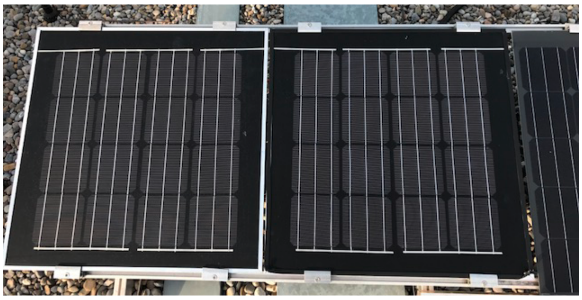

Fig. 4 Medium-area lightweight PV module composed of sixteen solar cells.

References

[1] A. C. Martins, V. Chapuis, F. Sculati-Meillaud, A. Virtuani, and C. Ballif, “Light and durable: Composite structures for build-ing-integrated photovoltaic modules” Progress in Photovoltaics: Research and Applications, pp. 1–12, 2018.
[2] A. C. Martins, V. Chapuis, A. Virtuani et al., “Thermo-mechanical stability of lightweight glass-free photovoltaic mod-ules based on a composite substrate” Solar Energy Materials and Solar Cells, vol. 187 pp. 82–90, 2018.
[3] A. C. Martins, C. Ballif (Dir.) and A. Virtuani (Dir.), “Glass-free lightweight PV building elements: solutions to minimize weight and maximize durability”, EPFL Thesis 9149, 2019.
[4] IEC 61215, “Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures,” International Electrotechnical Commission, 2016.

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Innovative Technologies 1.2

What is the novel generation of BIPV products?

In the last four years, multiple new technological solutions have emerged and become available for architectural integration. Here, a list of possible suppliers or partners is provided [1].

Products and solutions have been engineered and designed to make a new generation of PV products that should change the way people see – and think about – solar integrated in buildings. Transformative techniques were applied to modify the aspects of standard PV modules that can be mass-manufactured with standard processes. Novel photovoltaic elements for architectural integration into building rooftops and facades include white or terra cotta modules. Images can also be applied, in high- or low-resolution.

Keywords: Transformative techniques; White module; Terra cotta module; High- or low-resolution image.
Target audience: Regulation makers; Owners & other decision makers; Architects & engineers; Suppliers & companies; Broader public.

Fig. 1 Renovation project with large terra cotta tiles on a farmhouse located in Ecuvillens (Fribourg, Switzerland) (©Patrick Heinstein).

In terms of aesthetics, it seems difficult to reconcile conventional solar modules with roofs in rural or urban centers. Even with much goodwill in terms of architectural integration, black or blue glass surfaces sometimes reflect the sun intensely, inevitably giving rise to an impression of a foreign, even undesirable body attached to the building [2]. Moreover, until now, solar module manufacturers failed to offer visually and economically attractive solutions to replace the traditional, historic terra cotta roofs. Thus, in spite of decades of PV installations, it is only on very rare occasions that solar installations have contributed to the aesthetic improvement of the landscape. Very often, the contrary has been observed [3].

In reaction to this, a new generation of BIPV products has been developed to change the way people see – and think about – solar integrated in buildings. Transformative techniques are now applied to modify the aspects of standard PV modules that can be mass-manufactured with standard processes. For **roof application**, the most mature technology was developed in partnership with the industrial partner Issol and is now available on the Swiss market. It is a **terra cotta module** specifically designed for rooftops in architecturally sensitive areas (Fig. 1). These modules benefit from a robust material embedded between two glasses, which provides high mechanical robustness and leads to extended resistance to weathering stresses as compared to the standard glass/foil design of most commercial modules. The elongated rectangular shape of these modules along with their terra cotta color makes them resemble tiles, enabling them to be used on roofs in urban areas sensitive to traditional European heritage.

For **facade applications**, which are of particular value in high-density urban centers, where the ratio of facades to roof increases along with building height, several coloring techniques and types of substrates were developed to transform the visual appearance of standard photovoltaic modules (Fig. 2-3). The color white attracts particular interest, as it is widely used in architecture for its elegance, versatility and fresh look. A new technology developed by CSEM in partnership with the start-up company Solaxess is now available on the market. Solaxess' **white photovoltaic module** is a fully tempered, laminated safety glass, applied like traditional siding using the installation techniques specific to facades (Fig. 2). In regions where ambient temperature and indoor cooling is an issue, white photovoltaic modules are combining the advantages of power generation with an average reduction of 10°C of the building's temperature – which means that less energy is required to keep the building's indoor climate comfortable.

When colors besides white are preferred for a building facade, other coloring techniques are available. CSEM has achieved astonishing aesthetic results with the use of different types of foils inserted in the module. This concept is now under patent. Colored photovoltaic modules produced with this technique were displayed on a facade prototype during the Ecoparc Forum in Neuchâtel in 2017, resulting in much interest from visitors [cf sheet 5.4].


Fig. 2 The photovoltaic panels covering this facade were made by Solaxess (Neuchâtel) using CSEM technology (©Solaxess).


Fig. 3 Full-scale prototype of the 'Advanced Active Façade (AAF)' construction system (©Olivier Wavre).

Studies were carried out to check the material reliability of each coloring technique. Once the tests passed, reliability of full-size modules was assessed by exposing them to different conditions of accelerated weathering as advised by the IEC 61215 norm. The modules were characterized before and after degradation using visual inspection to detect any aesthetic defect, current/voltage measurement to assess performances and electroluminescence images. No visual change nor abnormal power loss were observed.

Images can also be applied onto a module in low resolution (for example, by digital ceramic printing on glass) or high resolution [4]. These approaches considerably increase the customization possibilities to match the building sector's needs, so that in theory, each part of the building exposed to sunlight could become a photovoltaic power generator. Combined with improvements in PV lifetime(up to 30 years and more) and reliability, there remain few limitations today to what the technology can offer to architects and builders [5].

References

[1] Terra-cotta modules (Solstis or Issol CH), white photovoltaics (Solaxess), solar tiles (Freesuns, Panotron), custom size modules (3S solar plus, Eternit, Solarwall, Sunstyle), colored PV (Issol, Glass Troesch, SwissInso).
[2] P. Heinstein et al, "Building integrated photovoltaic (BIPV): review, potential, barriers and myths," Green, vol. 3, no. 2, pp. 125-156,2013.
[3] E. Perret-Aebi et al. "Innovative solution for building integrated photovoltaics" Proc. CISBAT1, 2013.
[4] http://www.kaleo-solar.ch/fr/
[5] C. Ballif, L.-E. Perret-Aebi, S. Lufkin, E. Rey, "Integrated thinking for photovoltaics in buildings", Nature Energy, vol. 3, pages 438-442, 2018.

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Innovative Technologies 1.3

What is the long-term reliability of BIPV?

BIPV products in general are amazingly stable against UV and weathering. Typical guarantees of performance extend now for 25 or 30 years, ensuring profitability of the installation well after the end of the depreciation period [cf. sheet 4.4]. Here is a review of ongoing work in the field.

Long-term reliability and durability testing are critical to identifying product issues that may manifest in the field after several years. The main identified factors influencing BIPV lifetime, reliability and durability are high operating temperatures, non-homogeneous conditions (due to customization), regular shading, and mechanical and thermal stresses due to building skin.

Keywords: BIPV building skin; Active facade; Skin technology; Long-term reliability; Durability.
Target audience: Owners & other decision makers; Architects & engineers; Suppliers & companies.

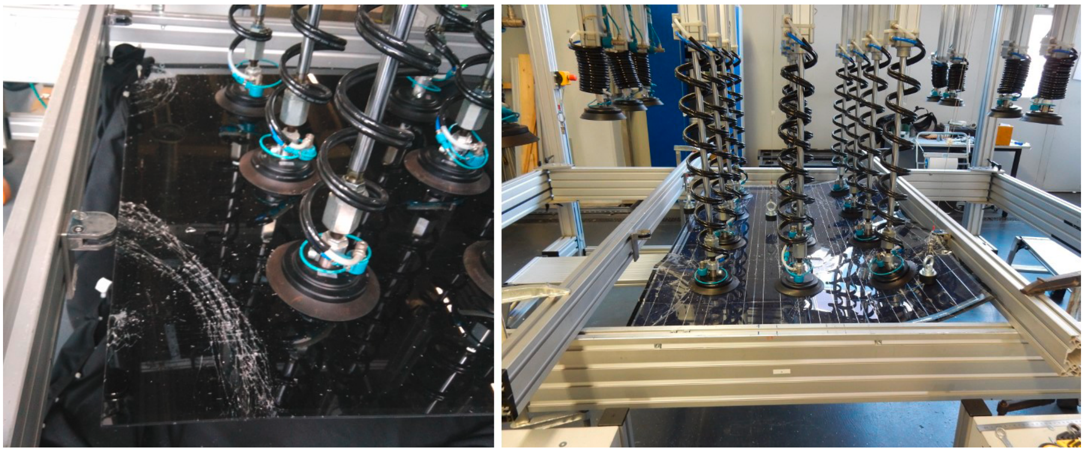

Fig. 1 Mechanical load on a PV module (©SUPSI).

EN 61215 and **EN 61646** qualification tests allow us mainly to identify initial **short-term reliability** issues of PV modules. Aging tests in climatic chamber and mechanical loads (Fig. 1) are also performed but it is important to note that there is no guarantee for PV modules to effectively sustain outdoor conditions and last for twenty or more years. Long-term reliability is a key issue for PV manufacturers and end-users. Nevertheless, it is not always considered in standards under preparation or covered by existing standards. For **long-term reliability** analysis, tests on PV modules are undergone by simulating accelerated stress tests based on measured data collected. Typical accelerating stressors are temperature, voltage, mechanical load, thermal cycling, humidity and vibration. Thus, in order to ensure long-term reliability of PV modules, it is important to identify their installation conditions and to adapt, accordingly, tests done indoors [1].

Moreover, there may be a need to differentiate between the **lifetime for generating electricity** (conventional PV) and the **lifetime and reliability as a building component** for a BIPV module. It remains to be seen whether the durability and reliability tests for conventional PV guarantee the performance of BIPV modules as part of building skin systems. Vice versa, it also remains to be seen whether the PV modules should undergo the same durability and reliability tests as their corresponding building element.

To combine the different functional requirements of **building technique and electrotechnic** in a BIPV product, BIPV qualification needs a special application.

According to EN 50583, Parts 1 and 2 "Photovoltaics in buildings", "Photovoltaic modules are considered to be building-integrated, if the PV modules form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011."

Testing and assessment of building-integrated PV products, according to the current standard, EN 50583: PV in Buildings, are conducted via an "adapted" application of IEC 61730/61215/61646 to building-integrated PV along with other qualification procedures/requirements for construction products. A list of current requirements for BIPV glass qualification is reported in [2] and includes the determination of:

- BIPV glass as laminated safety glass (EN 14449) for facades and overhead installations;
- watertightness against driving rain and uneven snow loads on roof systems;
- flammability and fire reaction/resistance of construction materials;
- noise insulating and absorption properties;
- dynamic wind stress tests according to window and facade standards;
- heat and light transmission;
- reflection properties;
- adhesive strength with tensile and shear load tests.

Today, we call for efforts to be made towards the **harmonization** and definition of **performance reference and procedures** for BIPV products. This not only calls into question the reference to building codes but also, in some cases, the definition of new procedures specifically developed for laminated BIPV glass and their particularities. Some examples for BIPV are [3]:

- dynamic mechanical load (new IEC TS 62782:2016)
- temperature ranges in existing standards (61215) due to increased operating temperatures of BIPV modules
- PV as a source-of-fire (arcing).

BIPV modules/systems should be envisioned and designed as building elements/systems in accordance with a **local and performance-based approach**, in order to guarantee the essential building requirements [4,5] and, at the same time, provide the necessary attention to the photovoltaic system.

The next challenge in the BIPV field, as also discussed in SP04, will be to identify missing gaps within the current standardization work and existing norms in relation to the most relevant BIPV requirements, performance risks, reliability and potential failure mechanisms to define which are the main routes for the development of new qualification procedures to support the market. Development and application of **adapted test methods for BIPV** is still a matter under investigation both at the lab/research level and within the standardization framework.

References

[1] CEA, Tecnalia, CTCV, Standardization needs for BIPV, PVSITES project, September 2016.
[2] https://www.tuv.com/media/corporate/industrial_service/solar_pv/Qualification_of_buidling-integrated_PV_TUV_Rheinland.pdf
[3] P. Bonomo, F. Frontini et al., Deliverable RM 2.2 Report on the identified BIPV constraints on solution proposed and their lifetime, ACTIVE INTERFACES R.M. 2.2
[4] P. Bonomo, F. Frontini, E. Saretta, M. Caccivio, G. Bellenda, G. Manzini, P.G. Cappellano, Fire Safety of PV Modules and Buildings: Overviews, Bottlenecks and Hints, EU PVSEC 2017, 2017.
[5] E. Saretta, P. Bonomo, F. Frontini, "Laminated BIPV glass: approaches for the integration in the building skin". In Jens Schneider and Bernhard Weller (Eds.), Engineered Transparency 2016: Glass in Architecture and Structural Engineering (363-372). Ernst&Sohn, 2016.

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Innovative Technologies

1.4

How can we integrate BIPV on vertical facades?

A full integration of PV is possible both in ventilated and more standard facades [1]. **Whichever the case, solution providers should be contacted in the early phases of the project** [cf. sheet 2.4]. **Some technical approaches are illustrated here.**

There are several barriers and constraints hindering the full implementation of BIPV into the building envelope, ranging from economic or financial barriers to legislative and institutional obstacles, or purely technical issues at both urban and building levels. A detailed study of building skin construction technology is therefore essential to analyze the relationship between the PV module and the different sub-systems and materials.

Keywords: BIPV building skin; Active facade; Skin technology; Urban and building barriers; Cost-acceptance.
Target audience: Owners & other decision makers; Architects & engineers; Suppliers & companies.

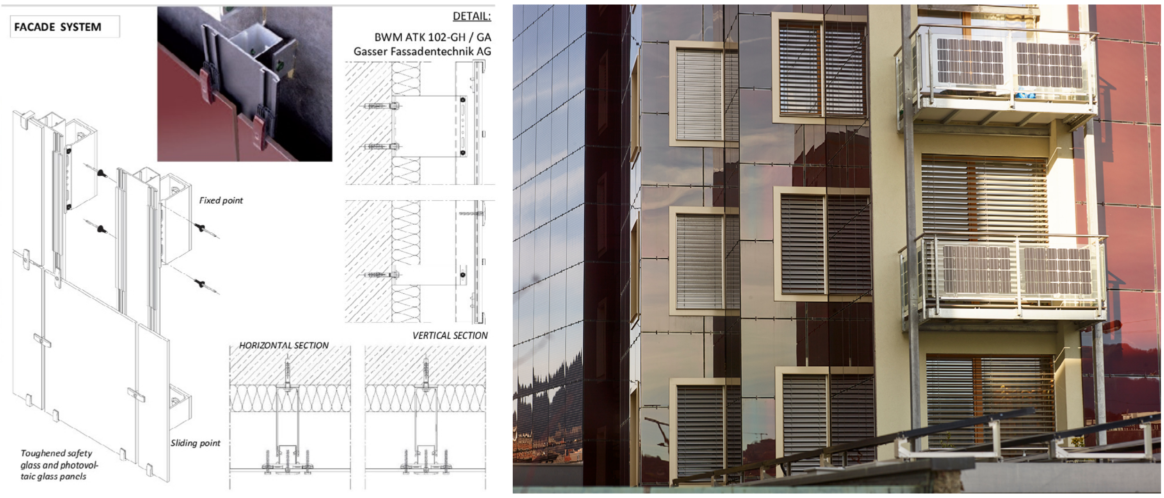

Fig. 1 Palazzo Positivo in Chiasso, Ticino. Facade details (©SUPSI www.bipv.ch; Gasser Gebäude AG).

Today's BIPV market can provide a clear catalogue of BIPV technical solutions, namely a structured scheme of elements to activate the building skin [2].

A detailed study of **building skin construction technology** is essential:

- to analyze the relationship of the PV part with the layerings, the different sub-systems and envelope materials;
- to define the construction interferences to be solved by the technical solution in order to properly satisfy the building's technological requirements (e.g. watertightness, mechanical stability, etc.) and PV functionality.

The **building skin engineering** should be a crucial step to consider both in R&D and in real Architecture, Engineering and Construction (AEC) processes, in order to evaluate all of the interacting construction aspects between PV and building envelope (such as physical integration, functionality, building/electro-technical requirements, cabling integration, etc.). Functionality, performance, aesthetics and energy use have to be assessed and addressed by a unitary solution.

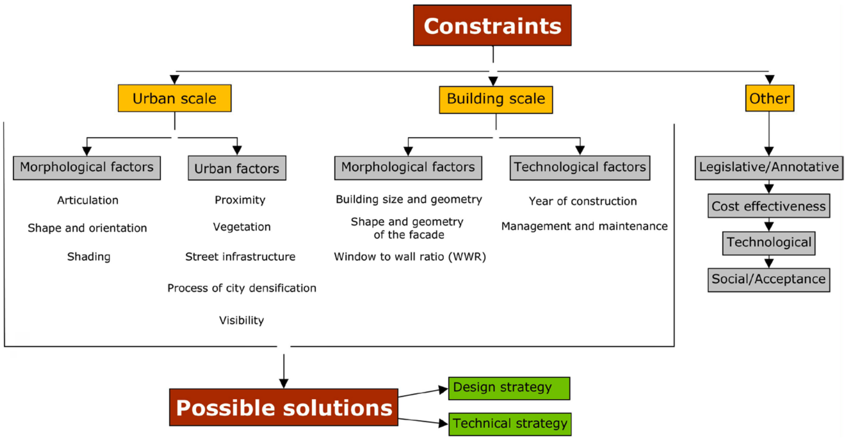

Fig. 2 Flowchart of main barriers for BIPV implementation (©SUPSI).

The topic of BIPV facades today demonstrates tangible **feasibility and design flexibility** [3,4]. However, some specific **technical requirements** (Fig. 1) and the related issues are often perceived as obstacles for the full implementation of BIPV in the existing built environment, namely in two specific contexts: the **urban** and **building** levels [5]. The former includes issues related to characteristics of the urban area where the building is located which can affect the BIPV concept and installation. The latter is related to the issues that arise when considering the specific building typology and building envelope for the BIPV installation (Fig. 2).

From project investigation it emerges that several **strategies to reduce or eliminate** constraints and limitations are possible, by implementing both a design and a technical approach.

- On the one hand, **technical solutions** such as accurate electrical wiring, the use of appropriate PV technology or technical devices (power optimizers, micro inverters, by-pass diodes, dummies) can moderate or eliminate some energy problems that building and urban situations create on a PV plant (shading, non-optimal exposure, etc.).
- On the other hand, implementing an accurate **BIPV design** approach during the early stages of architectural concept and building skin construction can help avoid some of the critical aspects affecting PV energy behavior, as can carefully taking into account some basic design rules and optimizing design factors such as PV plant configuration, geometry, exposure, string layout, etc. according to the urban or building context.

Our results highlight definitively that for technical, construction, energy and economic reasons [6] an integrated evaluation of BIPV in a broader building perspective is crucial. This integrated design must be the driving factor for supporting the growth of BIPV in the built environment.

References

[1] Several companies and offices can provide expertise in Switzerland, such as CR Energie, Solarwall, 3S solar plus, Viriden+partner (architecture), ISSOL CH, Ernst Schweizer AG, Basler & Hofmann, Solvatec, Solstis, etc.
[2] E. Saretta, P. Bonomo, F. Frontini. Active BIPV Glass Facades: Current Trends of Innovation GPD Glass Performance Days 2017. Tampere, Finland.
[3] A. Scognamiglio, H.N. Røstvik. Photovoltaics and zero energy buildings: A new opportunity and challenge for design. Prog. Photovolt. Res. Appl., 21, 1319–1336, 2013.
[4] D. Attoye et al. A Review on Building Integrated Photovoltaic Façade Customization Potentials, Sustainability 9, 2287, 2017.
[5] P. Corti, P. Bonomo, F. Frontini. Overcoming barriers for the BIPV diffusion at urban and building scale, 20. Status-Seminar «Forschen für den Bau im Kontext von Energie und Umwelt», 2018.
[6] P. Bonomo, F. Frontini, P. De Berardinis, I. Donsante. BIPV: Building Envelope Solutions in a Multicriteria Approach. A Method for Assessing Life-Cycle Costs in the Early Design Phase. Advances Building Energy Research, 2016.

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